

Pre- and Post-Settlement Fire Regimes in Mountain Big Sagebrush Steppe and Aspen: The Northwestern Great Basin

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Introduction

Fire is a primary disturbance process in sagebrush steppe communities, influencing plant dynamics, composition, and structure. The balance between woody and herbaceous vegetation is highly influenced by the length of fire return intervals. Fire regimes have changed since Eurasian settlement in the late 1800s (Gruel 1999, Miller and Rose 1999, Swetnam et al. 1999, Tausch 1999). As a result pinyon and juniper woodlands and shrub density and cover in the more mesic sagebrush steppe communities have significantly increased. Pinyon and juniper woodlands have expanded as much as 5 to 10 times in area and 2 to 20 times in density within occupied areas (Cottam and Stewart 1940, Burkhardt and Tisdale 1976, Tausch et al. 1981, Miller and Rose 1995, 1999). The majority of this expansion has occurred in the more productive mountain big sagebrush cover type. However, western juniper has also been actively encroaching into aspen, mountain mahogany, and riparian communities below 7,000 ft in the northwestern portion of the Great Basin (Miller and Rose 1995, Wall et al. 2001). Many private landowners and public land management agencies have been attempting to reintroduce fire to restore range health, improve livestock grazing conditions, and enhance wildlife habitat. However, knowledge and documentation describing pre-settlement fire regimes across different cover types throughout this region are limited.

Agencies use prescribed fire and other management tools to reduce fuel loads, restore the natural disturbance process of fire, and restore functional vegetation states. The federal agencies have also actively suppressed fires. Most of the fire/fuels management and restoration programs are based on little or no historical data. We lack the long-term information on shrubland/woodland dynamics, successional cycles, and associated fuel accumulation and fire regimes necessary for developing fire and fuels management programs that incorporate the appropriate spatial scales and return intervals. Information on pre-settlement fire regimes and the impacts of altered fire regimes on plant community structure and composition can be used to develop and support effective prescribe fire programs. In addition, this information can be used to increase public understanding of the role and importance of fire in these ecosystems. An effective public awareness program is key to reducing conflicts and challenge to active land management.

Objectives

The overall purpose of this study was to describe pre and post settlement fire regimes for the mountain big sagebrush steppe in the northwestern portion of the Great Basin.

Specific objectives were:

1. Document fire return intervals in mountain big sagebrush cover type.
2. Describe disturbance intervals in aspen communities in the northwestern Great Basin.
3. Reconstruct the pre-settlement fire regime for these two cover types.
4. Describe pre-settlement plant community structure based on past fire regimes.

Study Area

The study area was located in the High Desert and Klamath Ecological Provinces, which encompass portions of southeastern and south central Oregon and northeastern California (Fig. 1). Soils across the study sites are Argixerolls and Haploxerolls derived from igneous materials. Fire scar samples were collected across 10 stands representing the mountain big sagebrush (*Artemisia tridentata* spp *vaseyana*)/Idaho fescue (*Festuca idahoensis*) plant association. Bitterbrush (*Purshia tridentata*) was a codominant in several of the communities and curleaf mountain mahogany (*Cercocarpus ledifolius*) in one community. The presence of pre-settlement ponderosa pine (*Pinus ponderosa*) adjacent to or growing within these communities was the primary determining factor for documenting pre and post-settlement fire regimes for these communities. Disturbance intervals were also described for two aspen communities located in Harney and Lake Counties, Oregon (Fig. 1). The USDA Forest Service and USDI Bureau of Land Management manage the majority of these lands.

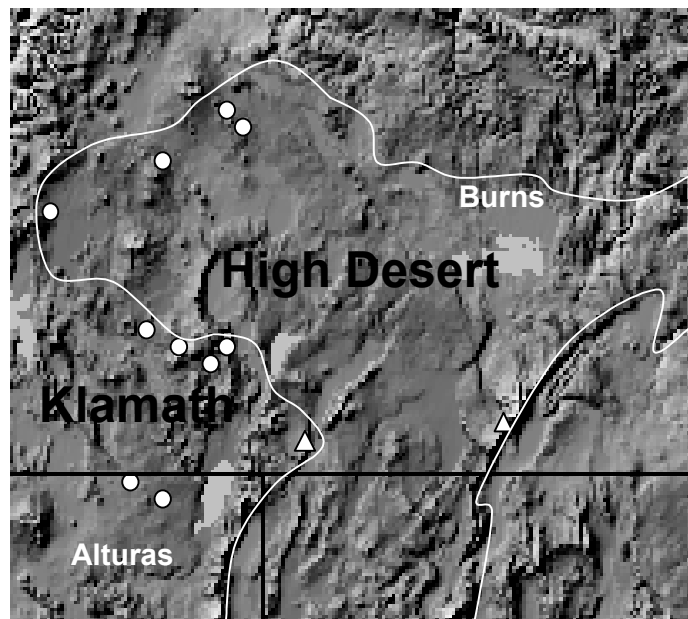


Figure 1. Mountain big sagebrush (○) and aspen (Δ) study site locations in the High Desert and Klamath Ecological Provinces.

Methods

Sample sites were selected opportunistically. We reconnaissanced a large region for pre-settlement ponderosa pine trees associated with mountain big sagebrush steppe communities. Fire scarred trees are scarce in these areas due to low tree densities and past harvest. Several of the sites were small islands surrounded by shrub steppe and currently being encroached by western juniper. Other sites, such as Pine Mountain and Dead Indian were located at the edge of a forest shrub steppe ecotone (Fig. 2). We sampled trees that were growing at the edge of the forest community, single trees growing in the adjacent shrub steppe community, and forest edges fingering out into the shrub steppe community. Our assumption was that fire did not stop at the forest edge or in some cases the micro community edge. Fuels were contiguous and in most cases ground fuels were heavier in the shrub steppe due to a greater abundance of shrubs and grasses than in the ponderosa pine understory. Similar age structure of post-settlement pine and juniper trees within forest and shrub steppe communities also supported our assumption that fire did not stop at the ecotone between the two communities.

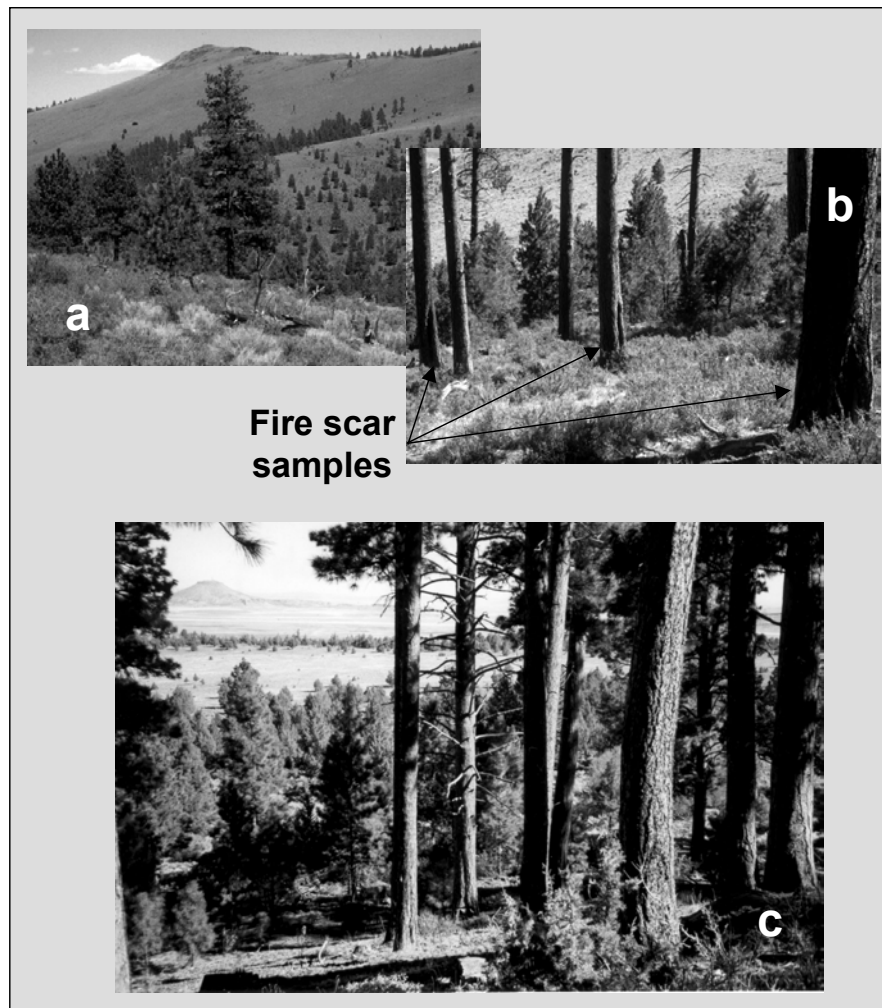


Figure 2. Pine Mountain (a&b) and Dead Indian (c) sample stands, with fire scarred trees in photo b.

Fire History

Mountain big sagebrush steppe and juniper woodlands - Fire scar samples were collected in clusters (< 1 ha) with $n=3$ to 5 trees per cluster where available (Fig. 2 & 3). Sampling in clusters provided a more complete record than individual trees due to the patchiness and variability of fire scarring among trees (Kilgore and Taylor 1979). Tree samples were prepared and measured as described by Arno and Sneek (1977) at the University of Arizona Tree Ring Laboratory. All samples were cross-dated with core samples collected from each site to identify the exact year of each fire event (Stokes and Smiley 1968). Fire frequency, fire interval variability, and season were determined for each cluster across the region. Season of burn was determined by the position of the scar in the ring (Fritts 1976).



Figure 3. Fire scar trees on the Squaw Mountain study site, last burned in 1938.

Aspen disturbance interval - To describe disturbance intervals in aspen within the northwest Great Basin, two large stands were sampled. The first, a continuous 71 ha stand, is located along Eusabio Ridge and Ankle Creek on the southern end of Steens Mountain southwest of Burns, Oregon (Fig. 1). The second, a series of adjacent stands totaling approximately 35 ha was located on Fish Creek Rim north of Adel, Oregon. Our assumption was the oldest cohort within a plot would provide an estimate of the last stand-replacement event (Romme et al. 1995). Our assumption and sampling procedures followed that of Romme et al. (1996). We also aged the oldest juniper trees within these stands to determine if the last stand replacement disturbance was fire, which would have

killed juniper, or disease or insects, which would have targeted only aspen. The Weibull distribution was used to determine the disturbance rotation period for aspen.

Aspen stands were systematically sampled by walking several transects from toe-slope to the ridge crest. Transects were placed every 80 to 100 meters across the length of the 3 km long stand. Along these transects, plots were established every 25 to 50 m. The variation in distance between plots was determined by stand structure; i.e., plots were centered in sites with similar tree density and tree size and not placed to overlap areas of varying stand structure. Within each plot, increment cores were collected from the 10 largest aspen trees to determine age distributions within the stand. A total of 128 plots and 1280 aspen were sampled across the two sites.

Data Analyses

The statistics module in the FHX2 fire history program (Grissino-Mayer 1995) was used to summarize and evaluate fire intervals and seasonality. Fire histories for all sites were split as pre-settlement, scars occurring prior to 1870, and post-settlement, fire scars occurring after 1899. The split was based on historical records documenting the arrival of livestock across this region (Oliphant 1964, Miller et al. 1994) and their impact on fire regimes through the reduction of fine fuels (Burkhart and Tisdale 1976, Miller and Rose 1999). We considered the time interval between 1871 and 1899 as an adjustment period. Miller and Rose (1999) reported that fire occurrence and size began decreasing during this time period.

Results

Approximately 200 fire scars were collected across eastern Oregon and northeastern California. The earliest fire scars collected were 1467 on Pine Mountain and 1517 in the upper Chewaucan River basin (Table 1). However, due to limited sampling depth and incomplete records (caused by burn-out of old fire scars by more recent fires) we calculated MFRI (mean fire return interval) across the 10 sites beginning between 1600 and 1830. Fire record lengths varied between 400 and 170 years (Table 2). Pre-settlement fire return interval (MFRI) varied between 10 and 20 years across sites, with exception of the Dead Indian study site where the MFRI was less than 10 years. Pre-settlement minimum and maximum intervals (years between fires) across the mountain big sagebrush / Idaho fescue cover type were 3 and 32 years. Due to the limited number of fire events occurring between 1900 and 2001 across all sites, MFRI could not be calculated for this time period (Figure 4). Fire occurrence was significantly less across all 10 sites between 1900-2001 compared to the frequency of events occurring prior to 1870. Fire has not occurred across 6 of the 10 sites during the past 100 years and only one or two fire events have occurred on the remaining 4 sites during this time period. The most recent fire event recorded occurred 50 years ago.

Table 1. Mean fire return intervals (MFI) and number of fire events across 10 mountain big sagebrush (bitterbrush) / Idaho fescue sites in central and southeastern Oregon and northeastern California.

Parameters	Site									
	Pine Mountain 1	Pine Mountain 2	Chewaucan Lower	Chewaucan Mid	Chewaucan Upper	Picture Rock Pass	Squaw Mt	Devils Garden	Dead Indian	Cinder Butte
Period	1740-1870	1626-1870	1780-1870	1650-1870	<i>Presettlement</i>					
# Events	10	17	6	19	20	8	10	4	7	7
MFI	12.6	14.8	17.2	11.7	14.1	16	12.2	17.3	6.2	16.5
Min Interval	7	4	12	3	3	5	7	11	3	-
Max Interval	23	32	26	28	25	32	25	25	10	-
Period	1900-2001	1900-2001	1900-2001	1900-2001	<i>Postsettlement</i>					
# Events	1	2	0	0	0	0	3	0	2	0
MFI	-	-					>34		>37.5	
Min Interval	84	36					15		8	
Max Interval		>50					>63		>67	
Last Event	1914	1950	1869	1897	1869	1863	1938	1871	1934	1860s
Sample Size	4	5	3	3	4	2	4	3	4	2

Table 2. Fire scar dates across sites.

Pine Mountain 1	Pine Mountain 2	Chewaucan Lower	Chewaucan Mid	Chewaucan Upper	Picture Rock Pass	Squaw Mt	Devils Garden	Dead Indian
	1467			1517	1751	1820	1802	1830
	1626			1527	1756	1828	1813	1835
	1661			1565	1771	1838	1829	1842
	1668			1592	1800	1845	1855	1845
	1710			1601	1810	1869	1871	1855
	1727			1610	1823	1883		1862
	1740			1632	1855	1890		1867
1742			1657	1657	1863	1900		1871
1755			1678	1678		1915		1875
	1759		1688	1688		1938		1893
1778	1778		1693	1693				1926
1785	1785		1703					1934
1793				1706				
	1796		1717	1717				
1807	1807		1723	1723				
1819	1819		1736					
1829	1829		1740					
1845				1743				
1855	1855			1757				
1886	1886		1768	1768				
1914	1914		1771	1771				
	1950	1783	1783	1792				
				1806				
		1809	1809					
			1814					
		1829	1829	1829				
				1839				
		1841	1841					
				1849				
		1855	1855	1855				
		1869	1869	1869				
		1879						
			1880					
		1889						
		1897						

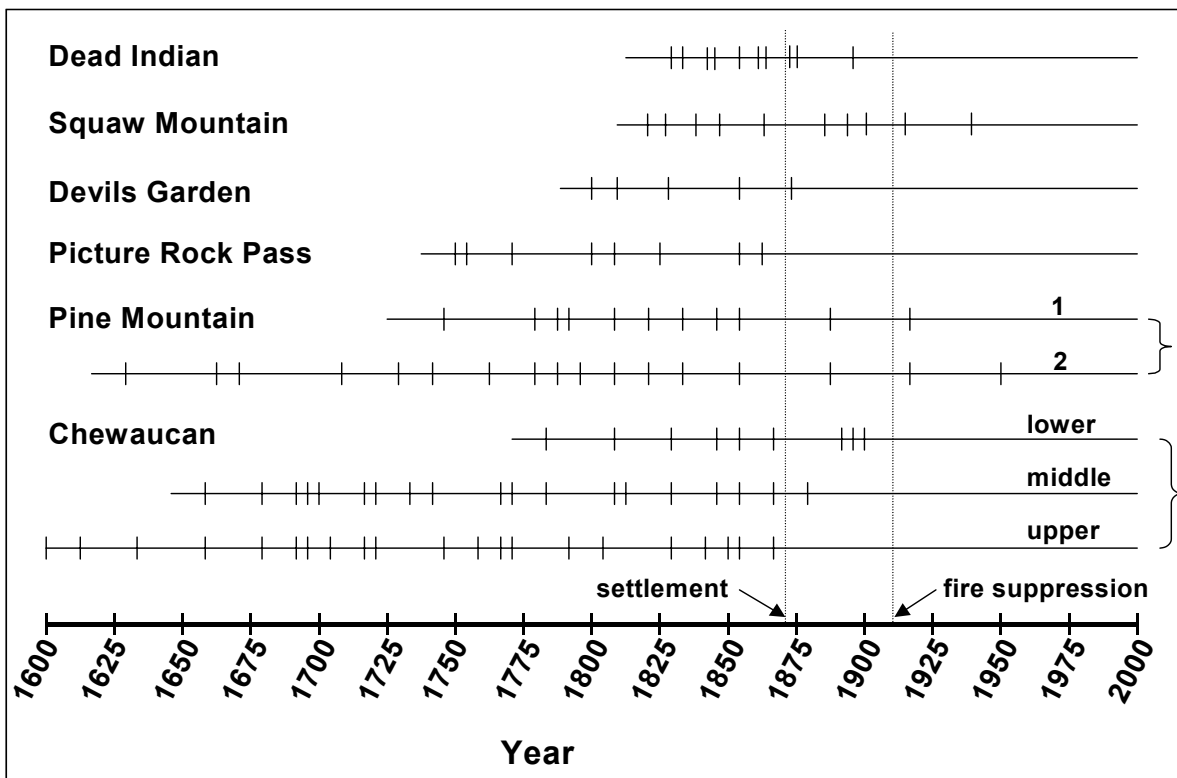


Figure 4. Chronology of fire occurrences among the different stands sampled in mountain big sagebrush / Idaho fescue plant association.

Individual Study Locations

Pine Mountain (Mountain big sagebrush / Idaho fescue)

Pine Mountain is located in the Deschutes National Forest in central Oregon (Appen. 1). The Prineville BLM manages adjacent sagebrush steppe lands located on the lower slopes. Samples were collected at two locations, West Basin Canyon (site 2) and the drainage to the immediate west (site 1), approximately one mile apart. The earliest fire scars collected were 1742 on site one and 1467 on site two (Table 2). Sampling depth was limited for the early fires on site 2 so fire return intervals were computed for the period after 1626. Successive fires between 1467 and 1626 damaged the catface on the tree with the 1467 scar.

Pre-settlement MFRI varied between 12.6 and 14.8 years across the two sites, with intervals ranging from as little as 4 to as long as 32 years (Table 2). All fires occurred between mid summer to early fall, with the majority occurring in late summer. There appeared to be an increase in fire events on site 2 between 1748-1870 (11.5 years) compared to 1626-1747 (19 years). However, the difference was not significant. Half of the pre-settlement fires occurred on both sites indicating an extensive burn. Fuels across this area are relatively contiguous and lightning strikes common during the summer. Fire events have decreased since the late 1800s. However, two post-settlement fires occurred across both sites in 1914 and 1950. The current plant community is a fully occupied by sagebrush (cover > 20%) with a young and open stand of juniper (< 5% cover).

Chewaucan (Mountain big sagebrush / Idaho fescue)

The Chewaucan River Basin is located in the Fremont National Forest and the Lakeview District of the BLM in south central Oregon (Appen. 2). Several fire scars collected were formed in the 1500s. However, because of limited samples during that period, MFRI was determined after 1600. The three study sites were located > 3 miles from one another. Pre-settlement MFRI varied from 11.7 to 17.2 years with intervals ranging between 3 and 28 years (Table 2). There appeared to be no change in MFRI during the early and later portions of the pre-settlement fire record. MFRI for the periods 1650-1759 and 1760 – 1870 on the middle site and 1600-1735 and 1735-1870 on the upper site were similar. The fire record for the lower site was too short to test for changes in pre-settlement MFRI. Three of the 11 fires occurring between 1780 and 1869 occurred across all three sites. Six occurred on at least two sites. No fires have occurred since 1900. Four small and low intensity fires occurred during the period of 1871-1899. All four fires occurred only on one site (indicating a small fire) and scarred only one tree (indicating a low intensity fire). Accelerated juniper establishment began in the late 1870s (Fig. 5).

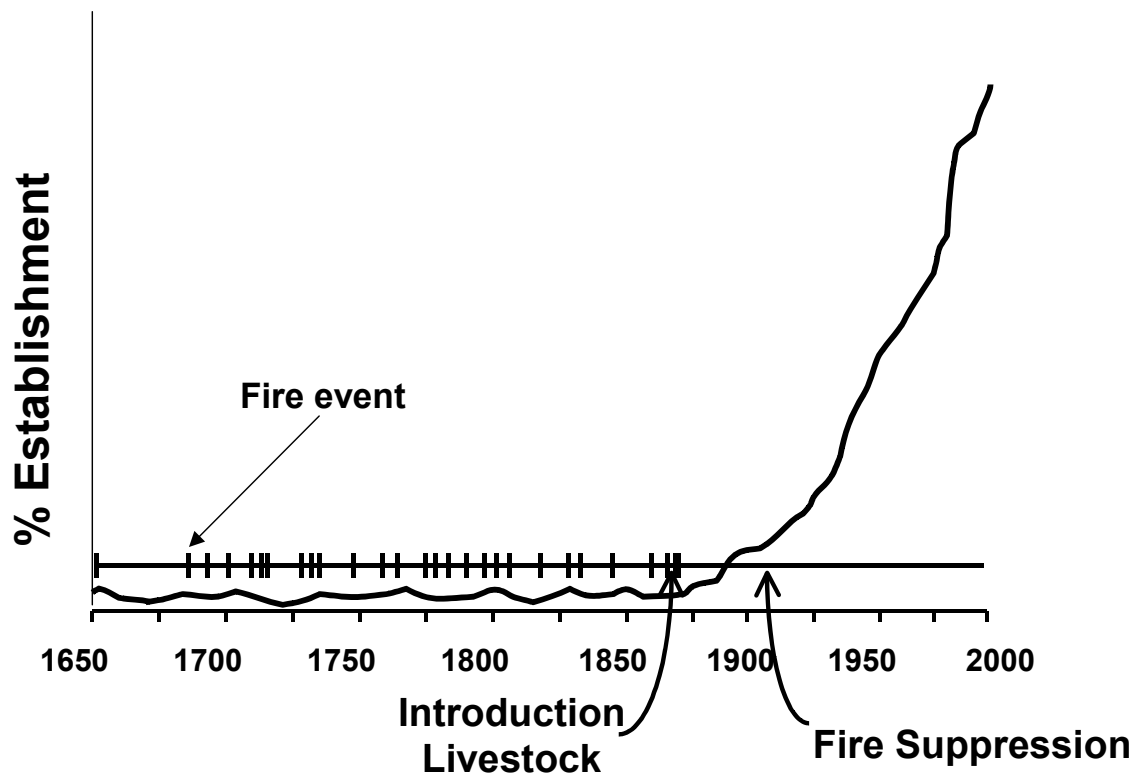


Figure 5. Western juniper establishment and fire chronology for the Chewaucan River Basin.

Picture Rock Pass (Mountain big sagebrush-curlleaf mountain mahogany/Idaho fescue)

Picture Rock Pass is located at the northern edge of the Fremont National Forest adjacent to lands managed by the Lakeview BLM District in south central Oregon (Appen. 3). Fire scar samples were collected from two trees growing outside the forest edge in the sagebrush steppe. Both trees died during the drying period of the 1920s. The pre-settlement MFRI was 16 years, with fire return intervals ranging between 5 and 32 (Table

2). A dense stand of mountain big sagebrush and mountain mahogany currently dominate the site. Western juniper is rapidly establishing in the understory. No fires have occurred since 1900.

Squaw Mountain (Mountain big sagebrush-bitterbrush/Idaho fescue)

Squaw Mountain is located on the southern edge of the Deschutes Forest and northwest boundary of the Lakeview BLM in central Oregon (Fig. 3, Appen. 4). Samples were collected from an open stand of ponderosa pine growing in a shrub steppe community. Pre-settlement MFRI was 12.2 years, with fire intervals ranging between 7 and 25 years (Table 2). Three fires have occurred since 1900, the last in 1938 (Table 1). Mountain big sagebrush, bitterbrush, and Idaho fescue currently dominate the stand. However, there are abundant western juniper trees less than 60 years old on the site.

Devils Garden (Mountain big sagebrush-bitterbrush/Idaho fescue)

Devils Garden is located on the Modoc National Forest in northern California (Appen. 5). Samples collected on the Devils Garden were small pine stands surrounded by sagebrush steppe plant communities. Pre-settlement MFRI was 17.3, ranging between 11 and 25 years (Table 2). The last fire occurred in 1871 (Table 1). The majority of the mountain big sagebrush communities are fully occupied by western juniper with less than 1% shrub cover in the understory. Expansion of juniper woodlands started in the mid to late 1870s.

Dead Indian (Mountain big sagebrush/Idaho fescue)

Dead Indian is a long ridge elevated above a high elevation tableland, located in the Fremont Forest, in south central Oregon (Appen. 6). Pre-settlement MFRI was 6.3, with intervals ranging between 3 and 10 years. The relatively short return intervals compared to the other sites may be due to its topographic position making it highly susceptible for lightning strikes. Current vegetation is a dense stand of mountain big sagebrush with an open stand of western juniper, most less than 50 years old. The last fire occurred in 1934.

Cinder Butte (Mountain big sagebrush-bitterbrush/Idaho fescue)

Cinder Butte is located in the Lakeview BLM District in central Oregon (Appen. 7). Both trees were growing in a mountain big sagebrush community. Fires were not dated but MFRI was 16.5 years. Fire has been absent on the site since 1900 until the area was prescribed burned in the mid 1990s. Prior to the prescribed fire the community was occupied by a dense cover of mountain big sagebrush (> 20% canopy cover) and a low density of western juniper.

Aspen

There were five distinct overstory age structures in the Eusabio/Ankle Creek aspen complex, on southern Steens Mountain (Fig. 6). Stand replacement disturbances with portions of the aspen grove occurred between 10 and 20 years. Based on this disturbance interval, the entire stand would be replaced approximately every 60 years. Although the age span is limited and occurs during active settlement in the late 1800s, stand age structure does strongly indicate portions of the overstory canopies were periodically killed. Similar results were attained for the Fish Creek/Cox Springs aspen complex.

Four age classes of dominant overstory trees were present, which established in 1940, 1900, 1880 and 1870.

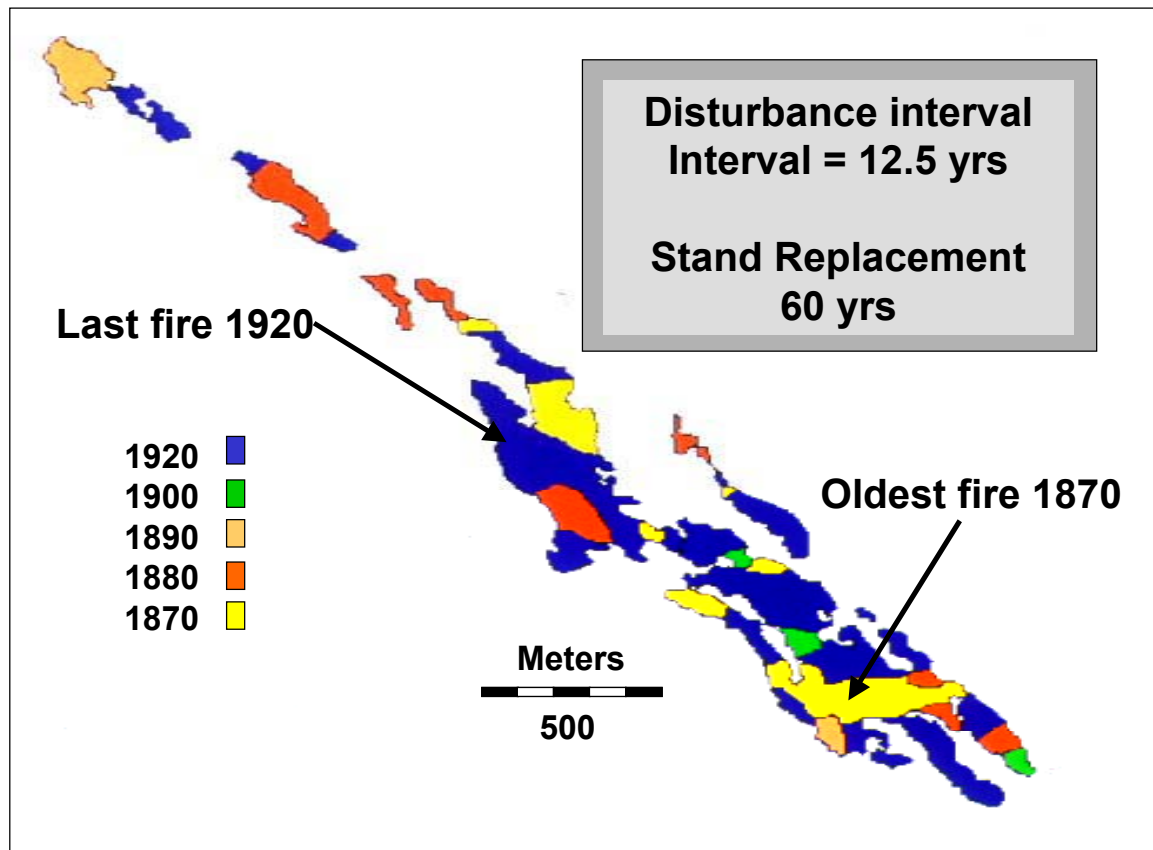


Figure 6. Seventy-one ha aspen complex on Eusabio Ridge Steens Mountain, Oregon. Different colors illustrate different age cohorts in the overstory canopy throughout the stand suggesting a stand replacement event.

Discussion

Mean Fire Return Intervals

Pre-settlement MFRI in mountain big sagebrush (bitterbrush) / Idaho fescue were consistently less than 20 years across the region, with the majority varying between 10 and 20 years. During the period between 1870 and the early 1900s the number, intensity, and size of fires began to decline. On the Chewaucan all the fires occurring during this period only occurred within one cluster indicating relatively small fires. In addition, the numbers of trees scared within each cluster were fewer, indicating less intense fires. By the mid 1900s fire events had significantly declined across the study area. Miller and Rose (1999) concluded that the introduction of livestock in the Chewaucan River basin in the late 1860s significantly affected fire return intervals through the reduction of fine fuels. Fire suppression in the National Forests began in the early 1900s; however, intensive suppression on rangelands did not begin until after World War II. Fire events become noticeably absent after 1950 across all sites (Fig. 4).

Only one spring fire occurred in the fire record across all sites for samples where time of year of the burn could be determined. However, spring fire events probably burned at relatively lower intensities, which may have caused less scarring of trees resulting in an underestimate of spring fires. Fires occurred from mid summer through late fall, with the majority in late summer. It is also likely the majority of fires were lightning caused. Dry lightning storms are common in mid to late summer across this region. During the period between August 5-20, 2002, 30,000 lightning strikes occurred in Harney County, Oregon with more than a 100,000 strikes in Harney and Lake Counties in Oregon and Modoc and Lassen Counties in California during this period (personal communication Burns BLM).

Pre-settlement Fire Regimes in Mountain big sagebrush (bitterbrush) / Idaho fescue

The results suggest the pre-settlement fire regime across much of this plant association was low intensity and highly frequent (Table 3). We propose that under the pre-settlement fire regime the majority of the mountain big sagebrush (bitterbrush) / Idaho fescue plant association was dominated by a herb layer with a widely scattered and patchy shrub layer (Fig. 7).

Table 3. Pre-settlement fire regime characteristics in the mountain big sagebrush (bitterbrush) / Idaho fescue cover type for the High Desert and Klamath Ecological Provinces.

Frequency	High (MFRI = 10-20 years)
Season	Mid summer through fall
Primary Ignition	Lightning
Size	Varied
Complexity	Varied
Severity	Low
Intensity	Low

Fine Fuel Component – The regular occurrence and relatively short intervals between fires would suggest fire events were highly dependent on the fine fuel layer. Short intervals provided little time for woody fuels to accumulate. The rapid decrease in fire events following the introduction of livestock in the 1870s and the significant correlation of at least one wetter than average year prior to the occurrence of a large fire strongly supports the importance of the fine fuel layer in this association (Miller and Rose 1999). The herb layer recovers rapidly following fire, providing a contiguous layer of fine fuel. Brown (1982) concluded that the fine fuel layer is the key component, which carries fire in most sagebrush grass communities. Only under extreme weather conditions during a fire event or where woody canopies exceed 35% does the overstory begin to carry the fire.

Woody fuel component - The dynamics and patchiness of the shrub layer under the pre-settlement fire regimes is difficult to predict and probably highly variable. Recovery of mountain big sagebrush and bitterbrush following fire is largely dependent on seed source on or within a short distance of the site. The majority of sagebrush seed dissemination occurs less than 3 m from the parent plant. So reestablishment is

dependent on plants surviving the fire or soil seed pools. Distance of bitterbrush seed dissemination is dependent on small mammals, which cache the seed. The continuity and high frequency of pre-settlement fires likely removed the majority of shrubs on the site. Under current conditions the sagebrush and bitterbrush layer rarely reaches full occupancy in less than 20 years (Fig. 8). In addition, shrub recovery prior to 1870 may have been slower than rates shown in figure 8. Shorter return intervals would have reduced the density of shrubs on a site resulting in lower seed input into the seed pool. Nearly 75% of the fire return intervals were ≤ 15 years prior to 1870. The shrub layer would generally be in the early stages of establishment.

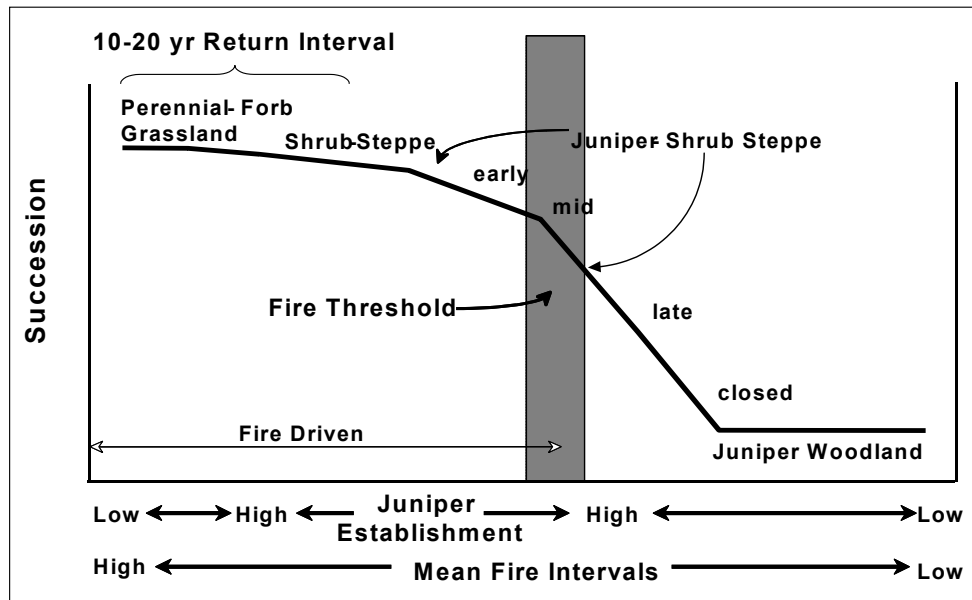


Figure 7. Conceptual diagram of changes in a shrub steppe community in the absence of fire (modeled after Archer 1989 from Miller et al. 2000). Succession would have persisted in the early portion of this graph due to the short fire return intervals. The fire threshold is crossed when understory fuels are no longer abundant enough to carry the fire.

The abundance of sprouting shrubs is also difficult to predict. Current work in several mountain big sagebrush stands found reestablishment of bitterbrush from crown sprouts compared to seed, accounted for only a small portion ($<1\%$) of shrubs reestablishing following a fire event. Current work also found sprouters such as green and gray rabbitbrush and horsebrush recovered more rapidly than sagebrush and bitterbrush but did not exceed preburn levels on sites in good condition in either the mountain big sagebrush / Idaho fescue and mountain big sagebrush / Columbia needlegrass plant association. In summary, we feel shrub density and canopy cover would have been relatively low and open under pre-settlement fire intervals compared to present day communities.

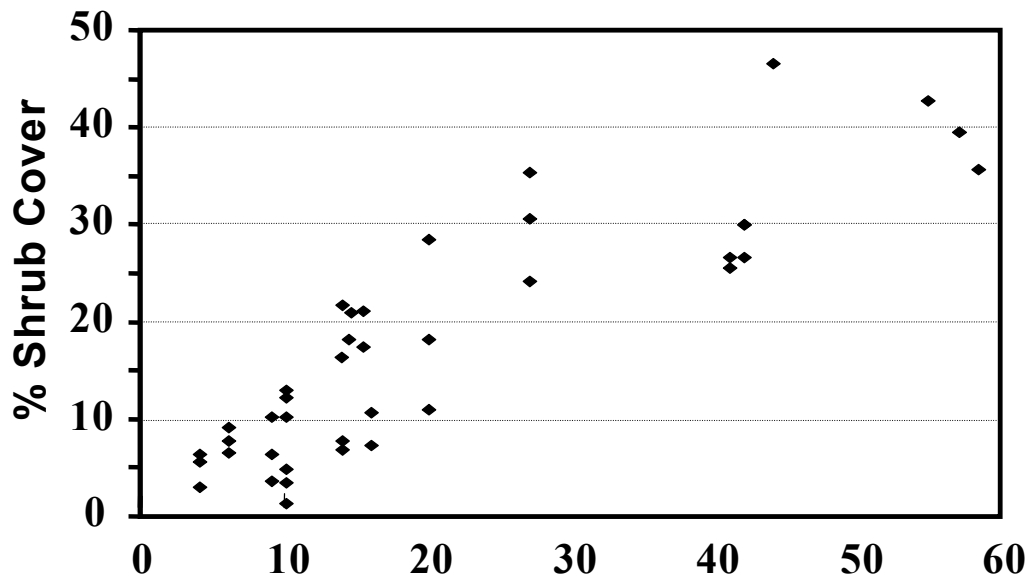


Figure 8. Relationship of sagebrush cover and years after fire. Full occupancy of shrubs is >30% canopy cover (Ziegenhagen 2002).

Tree Canopy - Western juniper age structure across this region and within the mountain big sagebrush (bitterbrush) / Idaho fescue plant association also supports the frequent occurrence of pre-settlement fires. There is no evidence to indicate juniper was common or codominant in this cover type prior to the 1870s (Burkhardt and Tisdale 1976, Miller and Rose 1995, 1999). Wood from large trees killed by fire can persist on a site for over 100 years (Miller and Rose 1999). The presence of old juniper on low productive rocky sites with limited fuels also supports the hypothesis that fires occurred on a regular basis on the more productive sites, limiting establishment. Miller and Rose (1999) concluded that the chronosequence of woodland expansion and the reduced occurrence of fire support the hypothesis that fire was a primary factor limiting juniper establishment in more productive deeper soil sagebrush communities (Fig. 5).

Climate and weather – Conditions of dry hot summers and dry lightning storms provided seasonal conditions for fires to occur, even in wet years. Climate and weather conditions also influence the size and complexity of pre-settlement fires. One third to half of the fires that occurred on the Chewaucan and Pine Mountain were extensive. Large fires were significantly correlated with wet years preceding the fire event in the Northwest (Miller and Rose 1999) and Southwest (Swetnam and Dietrich 1985, Baisan and Swetnam 1990, 1997). In a system where fine fuels are the primary component that carry fire and are often limiting, wetter than average years preceding the fire allow for the accumulation of fine fuels.

Aspen

Aspen has been declining throughout the West since Eurasian settlement (Baker 1925, Bartos and Campbell 1998, Mueggler 1989, Wall et al. 2001). In the northwestern Great Basin, western juniper has been actively invading aspen communities below 2135 m (Miller and Rose 1995, Wall et al. 2001). Fire has been reported to be an important

factor in facilitating the long-term presence and health of aspen across the landscape (Baker 1925, Bartos and Mueggler 1981, Jones and DeByle 1985, Brown and DeByle 1987, DeByle et al. 1989). European settlement has altered fire regimes through elimination of aboriginal burning, fire suppression, livestock grazing, introduction of exotic plant species, and urbanization of the West (Miller et al. 1994, Miller and Rose 1999). Herbivory and lack of fire are likely key factors in the recent expansion of western juniper and lack of aspen recruitment in communities throughout the northwestern Great Basin.

Age structure data from the Eusabio Ridge and Fish Creek Rim aspen complexes revealed 4 age cohorts in both aspen stands. Multiple-aged stands were lacking, suggesting stand replacement disturbance events rather than replacement over time due to gradual mortality. Kay and Bartos (2000) concluded that excessive herbivory on aspen creates even-aged stands and aspen protected from herbivory become multiple-aged stands. On the other hand, Jones and DeByle (1985) state that even-aged aspen stands result from a sprouting response after a fire and that multiple-aged stands result from a slow die-off of over-mature trees and the subsequent prolonged regeneration period. Several age structures in each stand suggest a stand replacement event across a portion of the stand at different times. The absence of juniper tree cohorts older than the 4 aspen cohort age groups suggest fire was the stand replacement disturbance. Age structure indicates disturbance intervals of 12.5 years within the stand and stand replacement at about a 60-year interval. In southern Colorado, fire had burned within a 77 km² aspen stand nearly every decade between 1760 and 1870 (Romme et al. 1996). Total stand replacement occurred about every 100 years.

In addition to fire; disease, insects, herbivory, and natural mortality influence aspen age structure. However, fire may have been the most frequent disturbance process. Fire return intervals in the mountain big sagebrush alliance were typically 10 to 20 years. However, fuel moisture in aspen stands is considerably higher than the adjacent shrub step communities so fire was probably patchier as suggested by figure 6.

Long-term browsing of aspen saplings by wild and domestic ungulates probably accelerates the process of conifer encroachment and eventual dominance of aspen communities. Continuous or heavy grazing of aspen suckers jeopardizes the health, recruitment, and longevity of the stand (Bartos and Mueggler 1981, Bartos et al. 1991, DeByle 1985, Romme et al. 1995). If regenerating suckers are unable to overcome browsing pressure, then aspen stands cannot sustain viable populations and persist amid the compounding effects of western juniper invasion and replacement.

The reintroduction of fire and the decrease of herbivore pressure are key factors in the restoration of aspen. To sustain or restore aspen, prescribed fire or allowed natural fires are the best tools for eliminating young juniper and inducing aspen regeneration. However, high fuel moisture in aspen communities commonly limits fire under more moderate prescribed fire prescriptions. In addition, ground fuels are usually limited in stands where juniper succession is in the late phase of development. These circumstances

necessitate cutting western juniper within the stand one year prior to burning in order to use their dried foliage to carry a fire.

Conclusion

Grasses and forbs dominated the physiognomy of the mountain big sagebrush/Idaho fescue plant association, (which may also include bitterbrush and curlleaf mountain mahogany) under the pre-settlement fire regime (Fig. 9). Since the majority of fire intervals were less than 16 years, the shrub layer was most likely open (<10%) and juniper trees rare. Reoccurring fires were low intensity and 1/3-1/2 were extensive indicating a contiguous fine fuel base. Shrubs and trees increased with the increasing length of fire return intervals after the 1870s. A dense shrub or tree layer currently dominates much of the mountain big sagebrush/Idaho fescue plant association. The herbaceous layer in this association recovers rapidly following fire. In addition, these communities are easy to burn if they have not crossed the threshold (Fig. 7). As communities cross the threshold and juniper begins to dominate the site, the rapid decline of understory fine and woody fuels (shrubs) greatly reduces the potential of wild or prescribed fires to occur. Usually some form of mechanical treatment is needed to get some of the trees on the ground to increase ground fuels.

The reduction in fire and increase in browsing by domestic and wild large herbivores are probably the primary factors leading to the decline in aspen throughout the West. Prior to settlement fires probably partially burned aspen communities creating a mosaic of different age classes. Pre-settlement aspen stands across the western landscape were probably characterized by multiple age classes of less than 60 to 100 years with stands over 100 years old rare.

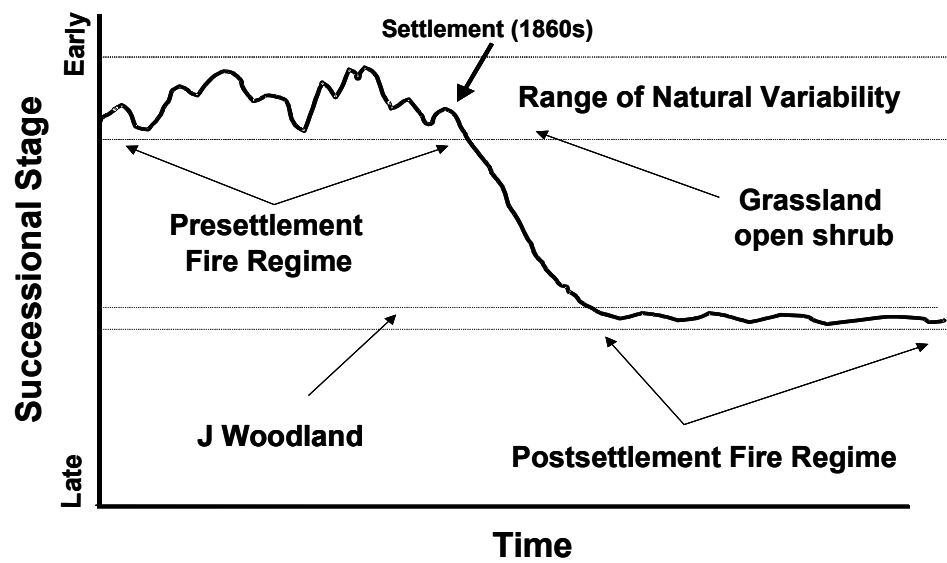


Figure 9. Conceptual diagram of the dynamics of a grassland shrub community under the pre-settlement fire regime and succession to juniper woodland under the post-settlement fire regime.

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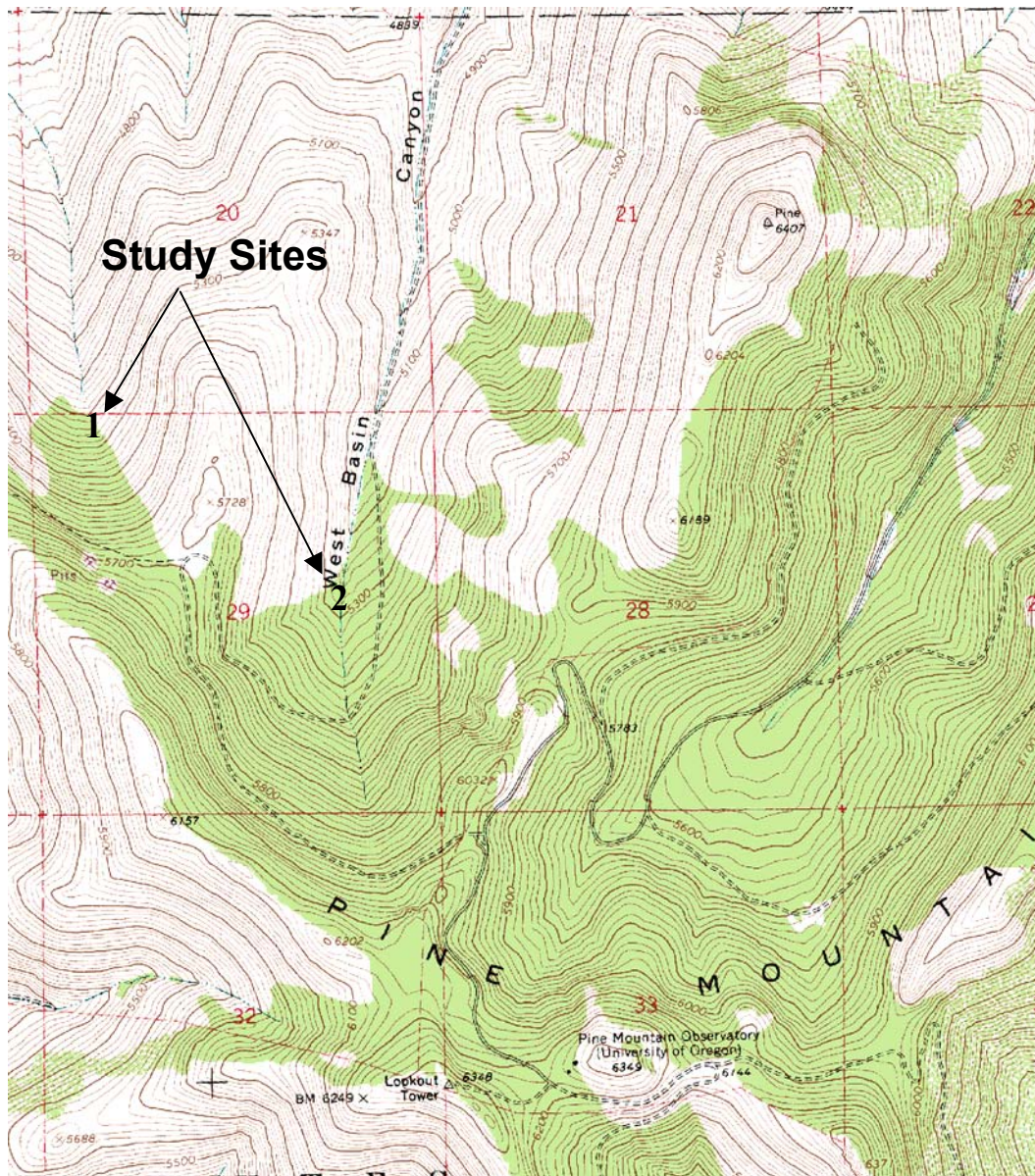
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Appendix

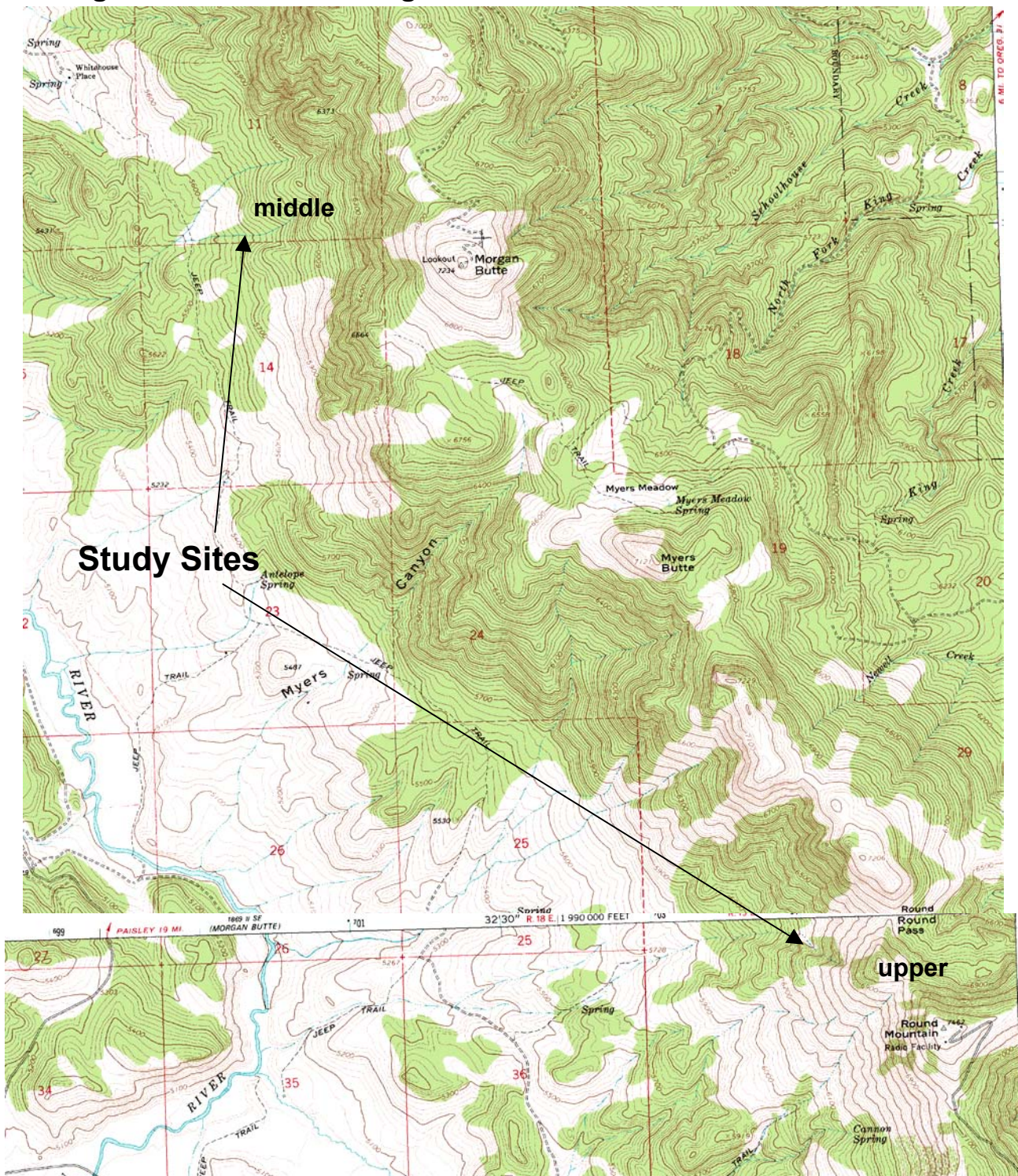
Appendix 1	Quad map of Pine Mt locations of trees.
Appendix 2	Quad map of Chewaucan River locations of trees.
Appendix 3	Quad map Picture Rock Pass
Appendix 4	Quad map Squaw Mt
Appendix 5	Quad map Devils Garden
Appendix 6	Quad map Dead Indian
Appendix 7	Quad map Cinder Butte

Pine Mountain



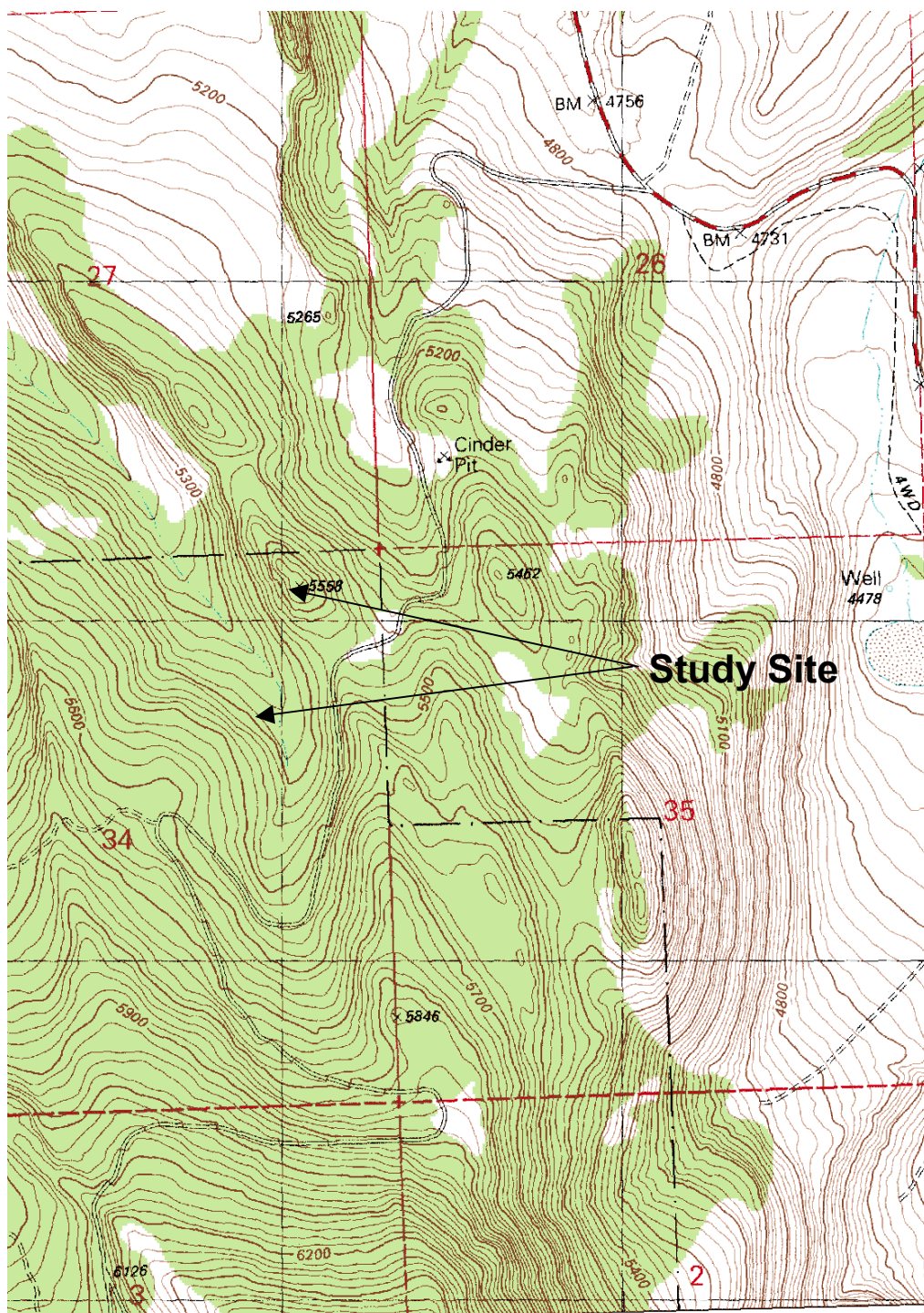
Appendix 1. Pine Mountain study sites; ponderosa pine – western juniper

Morgan Butte & Shoestring



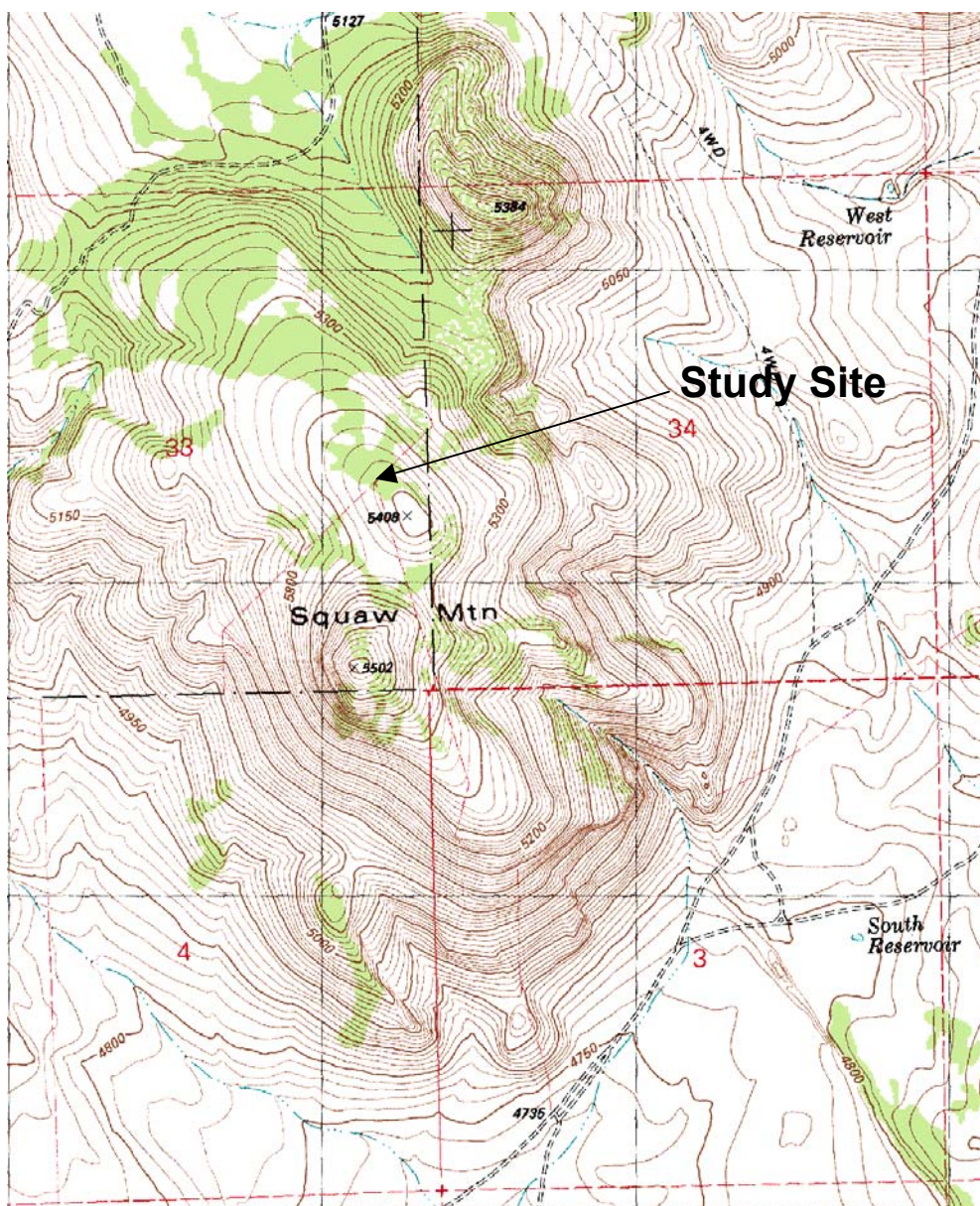
Appendix 2a. Upper and lower Chewaucan study sites; ponderosa pine – western juniper / mountain big sagebrush / Idaho fescue communities.

Egli Rim



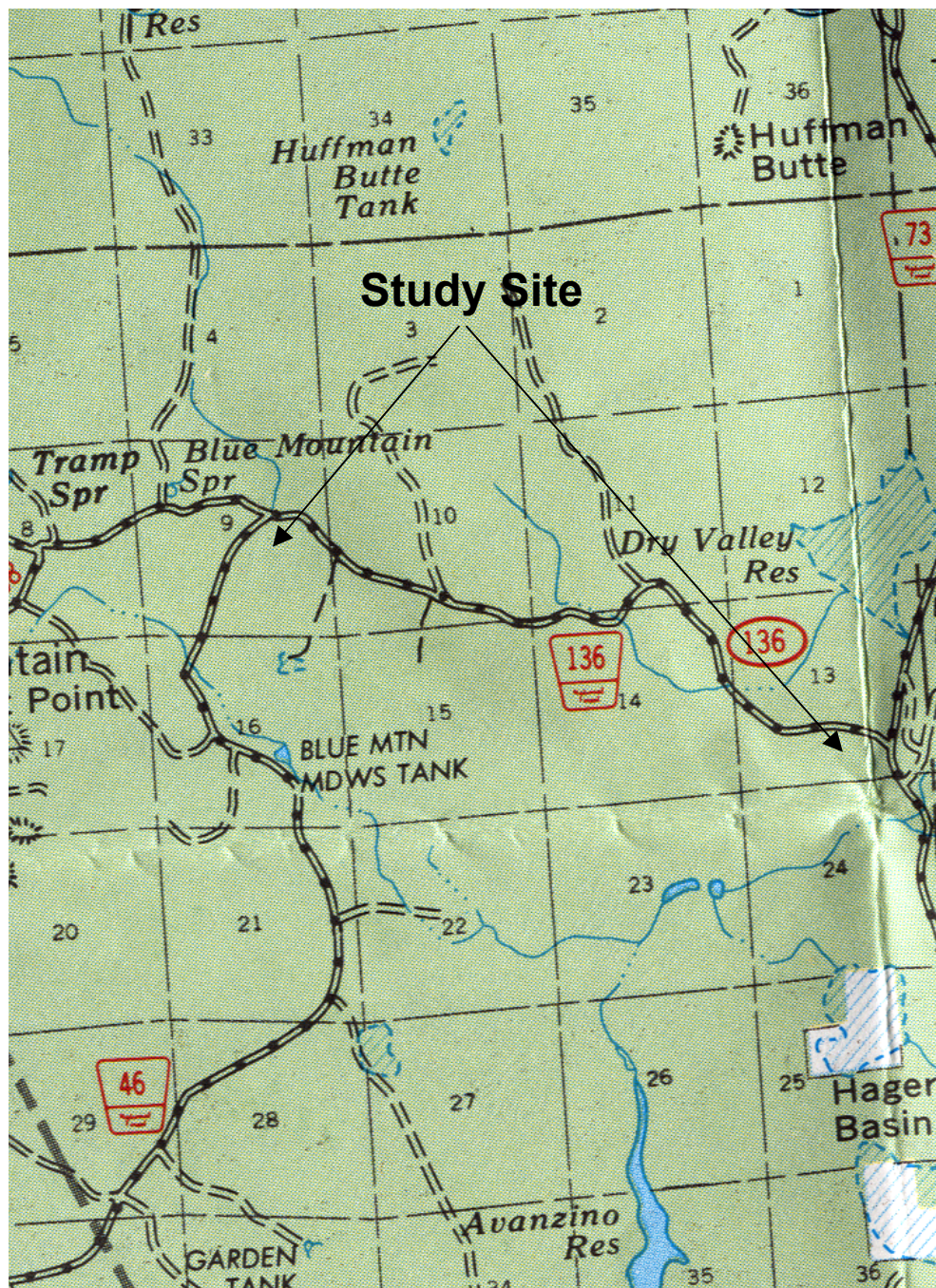
Appendix 3. Picture Rock Pass; ponderosa pine – western juniper / mountain mahogany – mountain big sagebrush / Idaho fescue community

Squaw Mt



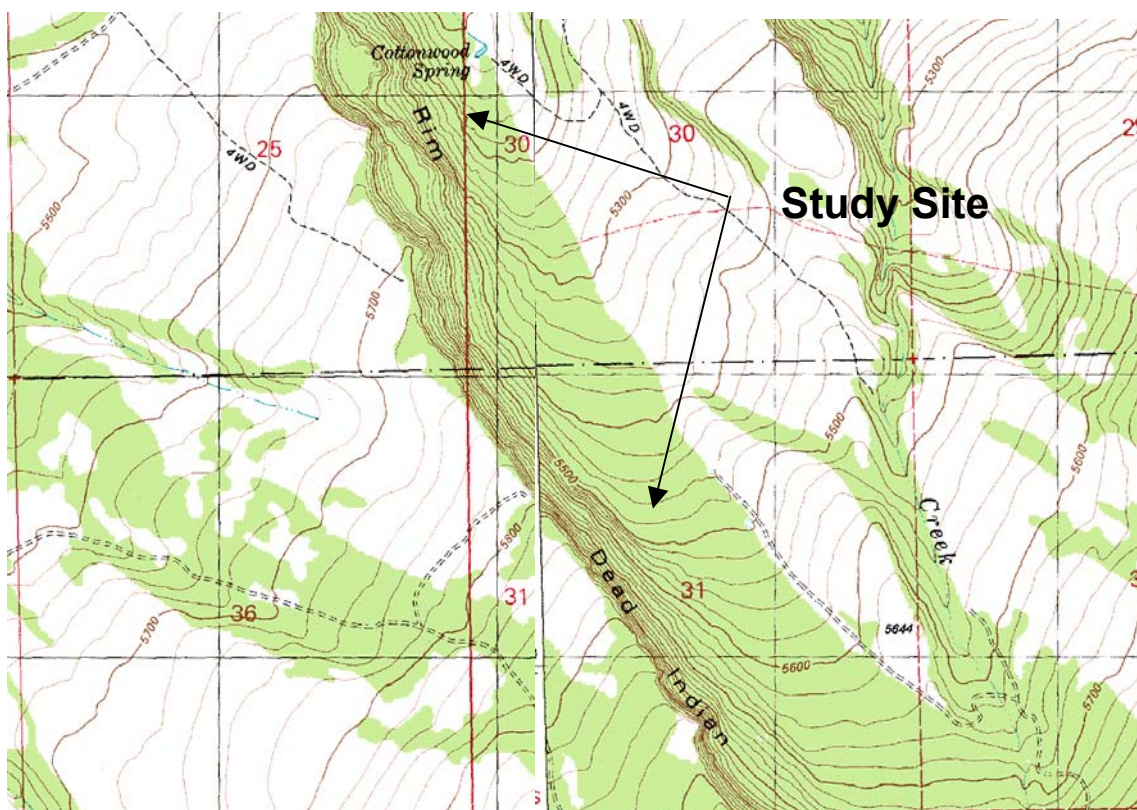
Appendix 4. Squaw Mountain study site; ponderosa pine-western juniper

Modoc National Forest,



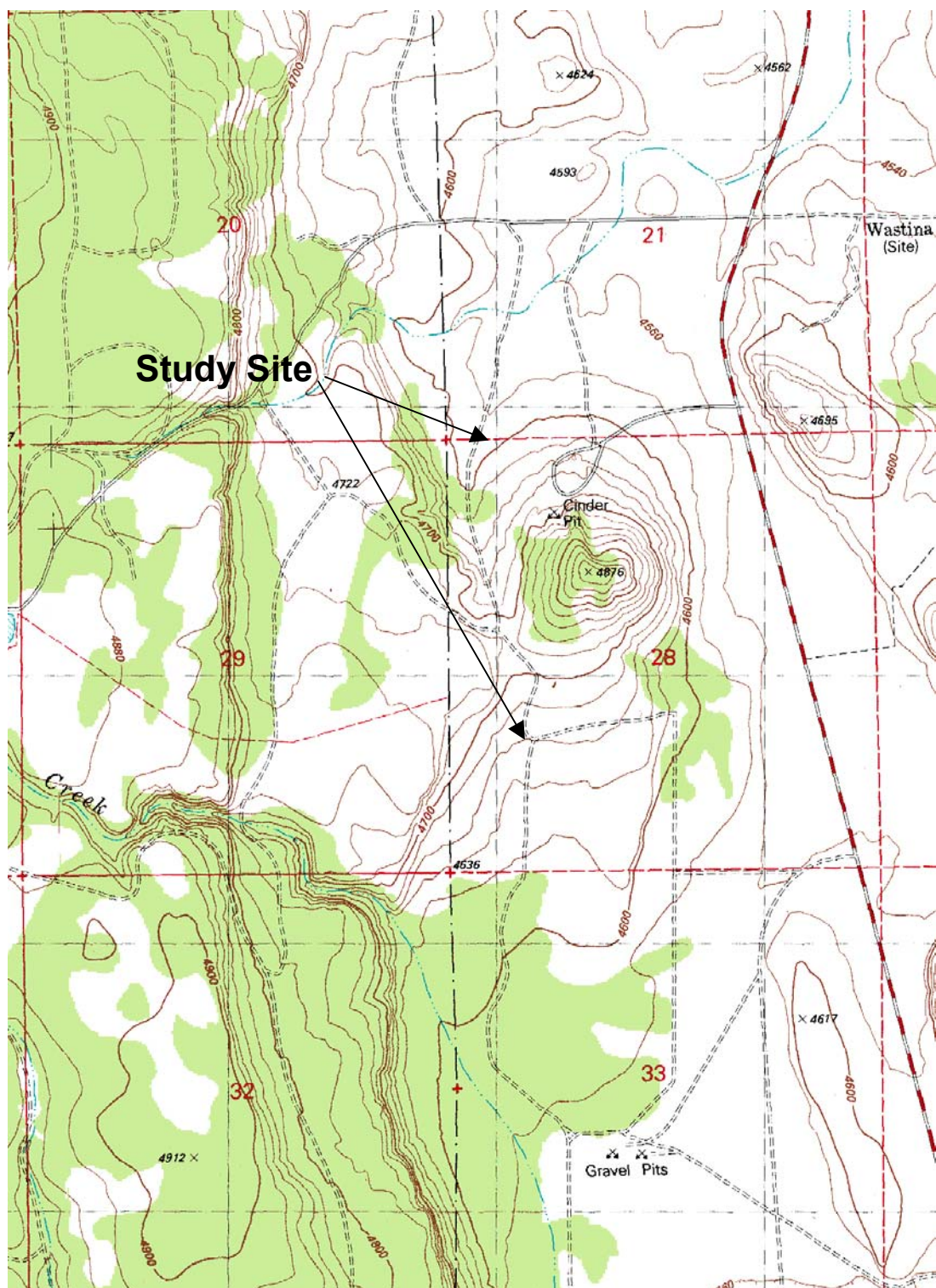
Appendix 5. Devils Garden study sites; ponderosa pine – western juniper

Duncan Reservoir and Egli Rim



Appendix 6. Dead Indian study sites; ponderosa pine – western juniper

McCarty Butte



Appendix 7. Cinder butte study site; ponderosa pine – western juniper